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ERGONOMICS APPLIED TO OPERATIONAL SYSTEMS IN SPACE STATIONS

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ERGONOMICS APPLIED TO OPERATIONAL SYSTEMS IN SPACE STATIONS

APPLICATION DE L'ERGONOMIE À DES SYSTÈMES OPÉRATIONNELS DANS DES STATIONS SPATIALES

Betty Ann M. Turpin

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ABSTRACT

This report outlines various aspects of operational systems in space stations as they influence, or are influenced by, operator performance and it discusses the application of ergonomics to the questions raised.

RÉSUMÉ

Le présent rapport décrit différents aspects des systèmes opérationnels des stations spatiales du point de vue de leur effet sur le rendement de l'opérateur, ou vice-versa, et il traite de l'application de l'ergonomie aux questions soulevées.

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ERGONOMICS APPLIED TO OPERATIONAL SYSTEMS IN SPACE STATIONS

1.0 INTRODUCTION

The purpose of this report was to integrate facts and findings, pertaining to ergonomics and the human role in space, into a discussion paper in order to bring to the forefront points at issue. To this end, it was deemed unrealistic to cover every issue, therefore the selection was based on the most pressing issues.

1.1 The Operator in the System

Human operators provide unique contributions to the total operator-machine system, such as superior decision-making and problem-solving abilities. They can process cognitive tasks in parallel and they can operate extremely well in complex systems. Most important of all, the human operator has the ability to respond to unforeseen occurrences. Conversely, human operators have weaknesses such as inferior computational abilities and a tendency to inattentiveness, and to ensure safe and efficient performance these must be guarded against.

Astronaut time is costly, and so are inefficiencies and errors (Regal, 1986). Human capabilities may be altered in space by environmental and task-related factors. Some of the most obvious effects of zero-gravity are to change human physical and perceptual abilities, and work schedules and tasks are more demanding. Fortunately, in many cases the impact of these and other environmental factors such as noise and radiation can be overcome by appropriate design approaches. Similarly, various other constraints, such as clothing, influence the design of workstations, tools, operator-machine interfaces, and communication techniques.

A more arduous design task is that of overcoming unusual demands on human perceptual capabilities, such as sensing outside the space suit, and contending with restrictions of visual range. On balance, however, the arguments for using and accommodating human operators in space are more compelling than the converse, even though human activities in space are restrained by the space environment and equipment. Tasks and machines need to be designed, therefore, to exploit the unique aspects offered by human operators, but, given the unique nature of the environment, special consideration needs to be given to all facets of human performance.

1.2 Adopting an Ergonomics Approach

The aim of the ergonomist is to analyze the complete system and to design it in a manner which maximizes its efficiency and safety. This is also, of course, the aim of the engineer and industrial designer, but different outlooks are adopted. While an engineer aims to design and build a system that can work (e.g., a space shuttle that will fly) the ergonomist aims to design the system so that it can be operated (e.g., a space shuttle that can be flown).

The basic premise of ergonomics is that knowledge about any one component alone - the operator, the machine, or the environment - is not sufficient to provide adequate understanding of the complete system. For complete understanding it is necessary to consider the complete system, including the operator in the loop.

The knowledge for understanding the human operator comes from several life and behavioral sciences: anthropometry and anatomy for seating, biomechanics for considering bones and muscles, physiology for energy demands of human motion, psychology for perception and decision-making, and so on. This expertise is not constrained by industrial boundaries. For example, research into the anthropometry of seating can be applied to office chairs as well as aircraft seats, and information about cognitive and sensory processing can be applied to typing and remote manipulator systems. Thus, ergonomics is relevant to any job or task.

The relevance of human factors to operational systems in space has been realized and acted upon by NASA. The goal of NASA's Human Factor Research Team Program has been to develop methods for determining which tasks should be automated, for designing safe tools and work-stations, and for determining which tasks should be conducted intravehicularly or extravehicularly (Hall, 1985).

1.3 Designing with Ergonomics in Mind

To design and implement a cost-effective space station operational system, it is crucial to establish performance standards and cost criteria. In terms of design, the primary task is to delineate the optimal role of each human-machine subsystem and interface. (The design must then be implemented, but implementation is outside the scope of this paper.)

NASA documents from the Johnson Space Center and the Marshall Space Flight Center give standards and guidelines for extravehicular activity from shuttles. Based on mission requirements assimilated from the past 25 years, they relate specifically to the space environment and human performance in space.

These standards will incorporate the experiences of recent space flights, data from other government agencies, and will consolidate several existing NASA standards (Miller, 1986). The studies attempt to eliminate obsolete or irrelevant data, resolve conflicting data found from other sources, and improve the method of presenting material to enhance its usability.

However, while there is an obvious need for ergonomic guidelines and standards, a simplistic acceptance of standards is basically naive. Good design requires a more analytic approach, against which the search for cookbooks that will provide all the answers for assessing human performance is essentially a exercise in futility.

Attempts to classify systems as manned or unmanned is, at best, misleading because at any level of system development a human component is involved, whether as designer, monitorer, initiator, or user, etc. Everything in human existence is done by, for, or against the human component (McDonnell-Douglas Astronautics Company, 1984).

The approach needed to design jobs, equipment, tasks, physical conditions and operating procedures, is that of fitting the task to the operator, not the converse. Very often only simple changes in a system are needed, but simple changes can eliminate unsafe situations and be cost effective. However, they should not be omitted just because they are simple, and one must guard against the tendency in design to look for more complex changes.

Technology develops at a remarkable and often overwhelming rate as, for example, in the computer industry. In using such technology space station subsystems should be designed to be safe, useful, capable of being easily and cost effectively modified if necessary. However, while technological advances have been remarkable, we should not be overzealous in putting them to use simply because they exist or because they are new. A more logical approach is to ask what is needed in order to build a particular system: if a technology does not exist, or if its present state is unacceptable, only then should it be developed. We must address the ergonomic questions that arise from technologies both old and new.

Changes in a system after implementation are often not welcomed, primarily because of their costs in time and money. Fortunately, this can be avoided by adopting two safeguards. The first is to build and test a prototype before the system is built. The second is to request or implement change, only if change can be shown to benefit operator performance. This latter approach, like the first, necessitates conducting a test program to ascertain whether or not the present design is inadequate and whether the new design will be better.

Test programs use several techniques. For example, mock-ups of systems are a useful design aid for studying access, layout, and other workstation problems (Turpin et al., 1987). Detailed drawings (not mere artist conceptions of what they think the system might look like) can give further assistance to conceptual development of the system. With both techniques it is important to ask what the mission objectives will be and what tasks the human operator will be required to perform.

In designing the arrangement of controls on a console the orientation of the operator dictates logical spatial relationships. The location of controls within the operator's workspace should be based on various criteria including functional groupings, sequential operations, operator body limitations, and methods of reducing errors (Turpin et al. 1987). The human operator should be considered to operate in parallel with other system operations, rather than as a component occurring in a series of system operations (Hall, 1985).

Consideration must be given to human performance requirements for intra- and extra-vehicular activity (IVA and EVA) respectively, while avoiding the tendency for general-purpose design. For example, given the different needs in task lighting and hand protection in IVA and EVA, similar display and control designs for both are probably inappropriate.

Operational systems can be further categorized into simple, moderate, and complex systems (McDonnell-Douglas Astronautics Company, 1984):

1. Simple systems
   - implementation of a single action
   - operations generally independent of other functions
   - unique applications, although basic principles are well understood

2. Moderate systems
   - multiple interacting functions and actions
   - complex control logic or networks
   - basic implementation techniques similar to previously developed systems

3. Complex systems
   - multiple interacting functions and actions
   - complex control of logic or networks
   - reduction to practice of design concepts

1.4 Monitoring and Measuring Performance

Recording performance outcomes for a given scenario is necessary but not sufficient. An understanding of how the operator obtained the outcome is needed, with a detailed account of the decision process. This is because operator-machine interfaces are becoming increasingly complex and determining which factor contributed to a specific outcome is crucial.

It is essential to estimate and compare measures for fine- and coarse-motor skills for IVA and EVA. In undertaking such a study in 1983, scientists at the McDonnell-Douglas Astronautics Company simulated activity within a space vehicle (IVA) by using a scuba environment and activity outside a space vehicle (EVA) by using pressure suits. By such means they measured, for example, the additional time needed to perform an electrical connection task outside the space vehicle. The simulated EVA data were compared with performance data gathered in an actual zero-gravity environment and the data showed that simulated measures provided reasonable estimates for zero-gravity performance times.

1.5 A Task-Orientated Taxonomy

Hall (1985) gives an example of a taxonomic approach to task analysis. He analyzed space station operations by classifying and assessing activities and their related operator-machine interactions, listing 37 generic classes of activities in terms of performance, pertaining to a broad spectrum of space station operational systems. He asked the following questions in relation to each mission objective:

1. Which of the 37 activities are involved in meeting the mission objective?

2. Which modes of man-machine interaction can meet the performance requirements of each activity?

3. Which man-machine mode represents the most cost-effective approach to the performance of each activity?

4. What is the state of technological readiness for the most cost-effective man-machine modes identified in step 3?

5. What is the relative degree of applicability of each man-machine mode in accomplishing the mission objective?

6. Which mode should be considered as the baseline for initiating the conceptual design of the system?

For each activity and category of operator-machine interaction (manual, augmented, supported, teleoperated, supervised and independent operations) the limiting human capabilities in terms of sensing, information processing, and motor actions were defined, as well as the human requirements for a given category of operator-machine interaction. Generally, response times were selected as the best indicator of performance. Table 1 shows data from two categories, illustrating this approach (Hall, 1985).

Tasks to be performed in space can be itemized and compared with similar tasks performed on earth, taking account of differences in the two environments. With this approach tasks could be simulated and performances compared noting differences and similarities between the two in terms of cognitive and movement requirements, how well mission objectives are met, and so on.

Table 1

Human Capabilities for Operator Machine Interaction

	Detection and Discrimination
Category:	Sensory/perceptual
Capability:	Brightness detection and discrimination
Characteristics:	brightness is measured in millilamberts rods and cones detect luminance
Limiting factors:	detection - wavelength of stimulus, previous light exposure, duration of prior exposure. discrimination - shape and size of stimulus, region of retina stimulated, level of illumination.
	Force Production
Category:	Psychomotor/motor capabilities
Capability:	Production and application of force
Characteristics:	muscle tension mechanical advantage optimum mechanical advantage strength - isometric and isotonic strength - concentric and eccentric force effort, work, endurance hand grip strength, back and forearm lift, pedal and lever force, finger pull, etc.
Limiting factors:	age and sex body build thermal environment acceleration

2.0 ASPECTS OF HUMAN PERFORMANCE

2.1 Vision

While changes in visual perception have been noted on entering space, astronauts usually adapt within a few days or weeks, depending on the dsyfunction. So far these dsyfunctions have not proven to be serious or to yield serious consequences, but they can cause difficulties and need to be taken into accour t when designing space equipment.

American astronauts and Soviet cosmonauts have noted minor losses in visual acuity when vieving near objects. Contrast sensitivity has shown the greatest change in terms of space adaptation. There are limited brightness cues and a wider range of light intensities than that found on earth.

Astronauts have reported seeing starlight flashes which are believed to have resulted from particle radiation traversing the head and stimulating the retina or other parts of the visual system (Regal, 1986). Astronauts have difficulty determining with certainty the distance, brightness, and size of objects. This, in turn, has caused disorientation and erroneous perception of depth. There are limited positional cues, such as those which indicate "up" and "down". The recognition of otherwise familiar objects has proven difficult. The space environment is without haze, lacks horizon cues, and has limited foreground and background cues, all of which are used to provide distance cues.

On earth visual certainty is facilitated by making head movements. However, in a confined space suit, because the helmet must move with head movement (in order to keep the face plate in line with the eyes, vision is restricted by the face plate). This has meant that, contrary to accepted ergonomics principles, visual access has been based on the design of the helmet rather than on human visual capabilities. This is the old problem of fitting the operator to the designed equipment, rather than reconsidering what design alterations or what new designs would best accommodate the operator's visual system.

2.2 Feedback

Feedback serves to monitor performance either for control purposes or for assessing performance accuracy. Feedback may arise from internal sources, such as the tactile and kinesthetic sensory systems, or from external sources, such as augmented visual displays, buzzers, and weight-bearing sources. These external sources are artificial sources of feedback but, of course, are perceived like the internal sources through the sensory systems. Feedback monitoring can be ongoing, providing closed-loop control, or it can occur at the termination of performance, providing open-loop control. Open- and closed-loop feedback control may occur simultaneously for a given action.

Providing external sources of feedback must be done efficiently. It is pointless to present, say, visual information alone if in fact auditory information would be more efficient and useful. It is crucial to determine the appropriate feedback for control of a subsystem such as a remote manipulator, and this implies collection of empirical data.

Informational feedback in an interactive system includes input and process verification, the present and past state of the system, and the recall of stored data. One must determine whether to present this information in analogue or digital form and to which sensory system. For example, how should information normally provided tactually and kinesthetically by direct contact (as in lifting a weight) be provided when controlling a remote manipulator. In this case operators must be able to manipulate, move, extract, position, and perform other dexterous tasks in both inter- and extra-vehicular activities. How effectively remote manipulators add versatility to space station operational system's effectiveness depends largely upon the feedback accompanying control. Techniques are being developed to address the problem of extracting cognitive and sensory task information, using ecologically more valid applications (Nicogossian, 1984).

2.3 Errors

From an ergonomics point of view operator errors occur because information exchange in the perceptual, decision-making or motor processing systems is inadequate, owing either to an internal failure or to some environmental influence.

Researchers have attempted to classify errors, with some degree of agreement among themselves. Norman (1981) distinguishes between selection, execution, omission, and intrusion errors, and this classification may prove useful in understanding why and how errors occur, as well as in facilating training and development. Performance usually fails not because the wrong response has been executed, but because the right response has occurred in the wrong place or at the wrong time. Motor errors, in which a correct response is selected but an incorrect response emerges are perhaps the most difficult kind to deal with.

Evidence shows that operators are able to detect the occurrence of an error even before it has overtly occurred. Subjects can correct an error response faster than it would have taken them to initiate a correct response in the first place (Rabbitt and Rodgers, 1977; Rabbitt and Vyas, 1981). These data support the idea that decisions about the accuracy of a response occur well ahead of movement initiation and termination, and that error monitoring is continuous and even planned for. In order to detect the occurrence of an error, whether before, during, or after an action, an error monitoring system must exist and this system must be separate from the control system (Norman, 1979).

A wide range of domains has been scrutinized for data on error performance, including aircraft control, process control, domestic tasks, typing, ship operation, human-computer interaction, and others. Errors are rarely random or unsystematic occurrences, but can be traced to causal factors that, when discovered, may be avoided by the operator (Turpin and Buck, 1984).

In most cases the consequence of human error is a mild upset in operations. In other cases the consequence is more spectacular or tragic. Very often, arising from investigations of malfunctions or disasters, the term "human error" has commonly implied carelessness or incompetence on the part of the operator. Ergonomics takes an opposite and more positive attitude, in that these errors are caused by circumstances that can be anticipated and prevented given sufficient attention to the relevant human factors (Buck, 1986).

In the case of the capsize of the Ocean Ranger, for example, the investigation found that to determine the current draft of the rig, operators in charge of ballast control had to look out a porthole located in one of the legs over 8 meters above mean water level. This led to the habit of leaving open the deadlight which protected the porthole, and consequently water entered, damaging the ballast control system. Furthermore, operators were provided with confusing information regarding ballast control. Both of these design inadequacies increased the likelihood of a disaster occurring.

Human errors are fundamentally quite different than those of machine and system errors. Not only do human errors arise from different mechanisms than mechanical errors, but the manner in which human errors are handled and the ramifications of such errors are quite different. When a machine or system fails the failure is usually isolated and can be identified, and operations can be ceased. Isolating and identifying human error, by contrast, is a more difficult and complex task, and the occurrence of one human error may lead to additional errors, with a compounding effect on the system.

Machines are not able to anticipate the possibility of malfunction, but human processing permits the potential for anticipating errors and corrective actions. It is doubtful that robots or an automated system will be able to accomplish this to such a finite degree. Because, unlike machines, operators can monitor, detect, and often correct their own errors, a system should be designed with provision for human intervention. The alternative is to build in redundancy and elaborate error detecting subsystems.

2.4 Methods of Assessing Errors

Errors are often retrievable and accidents are fortuitous, although in most cases not all errors lead to accidents. Near accidents are more numerous and offer a more extensive, complete source of data. Three methods to study errors and accidents exist: clinical, epidemiological, and experimental (Buck et al, 1986).

In the clinical technique the immediate antecedents of an event are examined after the event. This technique is often the only means of assessing an accident, as in the Challenger disaster. Unfortunately, with this technique an important but undetected source of data may be overlooked. Ergonomists may contribute by adding particular insights into the diagnosis.

In the epidemiological technique factors associated with errors or accidents are described and common features of these errors or accidents are enumerated. While this technique may provide information for preventive intervention it may not necessarily provide a complete understanding of the problem. Again, ergonomists may contribute by analyzing informational and environmental factors.

In the experimental technique causal factors can be addressed more thoroughly. To achieve this one must study the task and treat errors as a normal occurrence. Ample data exists indicating that errors are not random occurrences, and therefore, the factors causing an error can be detected. This technique has the potential of providing a clearer understanding of the problem.

3.0 ERGONOMICS AND OPERATIONAL SYSTEMS

3.1 Computers and Automation

Developing a space station resembles the development of any terrestrial operational system in terms of the increasing complexity of, and reliance place upon, automation and computers. Since the space station operational system will function under the supervision of both ground based and space located operators, one critical issue is that of determining policy-generating procedures which will balance the crew's level of dependency on ground control. This should be based on criteria relating to the capabilities and limitations of the crew and space station.

Software-derived control and display systems are flourishing and all-purpose, flexible workstations are designed. However, it would be inappropriate to assume that devices and displays used on earth will necessarily be suitable in space. Consequently, assessment of the compatibility of a device or display to the environment and the operator must be made.

New technologies will be required and increased demands on existing technologies is inevitable. The most important consideration here is to provide for the implementation of changes and the integration of new technologies, rapidly and with as few major changes as possible.

Implementing automation and insuring the human supervision of these complex, high-risk systems is based on the rationale that the new system will be more efficient and reliable. This will depend on investigations into the methods required to display integrated dynamic-system relationships and processing in a manner that the operators will be able to understand (Firschein et al., 1986).

Computers have simulated human performance, perhaps to the extent of replacing the validation and empirical testing of human performance. Simulation enhances productivity in terms of cost/benefit analysis and feasibility, and is useful, because it is usually too expensive or impractical to collect empirical data in the real world.

Nonetheless, the quest for automation and the utilization of computers raises some serious concerns. The assumption made is that automating or computerizing a system will eliminate the operator. This could be no further from the truth because, even though the trend indicates a shift in the role of the operator, at some point the system still has to be built, programmed, maintained, monitored and supervised by operators. In any case, a system is seldom fully automatic and the machine and human components must be symbiotic, with subsystems complementing human cognitive and motor capabilities rather than attempting entirely to replace them.

Assuming that "all bases are covered", and that all aspects of control will run smoothly because the system is automated, overlooks the possibility that a case has not been programmed into the system, because it was not initially thought of. It is doubtful that all emergency procedures will be automated, because not all situations can be logically anticipated and the human information processing system will be needed to deal with this. Critical decisions must remain the prerogative of the operator. A notevorthy report from one of the astronauts on the STS-9 flight substantiates this statement: "I can think of five cases where people doing the job saved the day."

Perhaps the most outrageous assumption is that using computers will automatically yield an intelligent system. The old adage "garbage in, garbage out" remains valid and that a system is only as good as its programmer's expertise and capabilities.

3.2 Expert Knowledge-Based Systems

It is commonly assumed that an expert system 'reasons' in a manner similar to that of a human expert. However, the fact that a computer arrives at the same answer as an expert does not necessarily mean that it arrived at the answer in the same way. It does not follow that a computer can do all the things a person a can do. One can never be certain that all expert knowledge has been embodied into the system (partly because the expert may have forgotten that he knew it), and this will never be known until you ask the system for the answer to a problem whose solution requires access to the knowledge that was not included.

The task of capturing the knowledge and rules used by experts to arrive at a decision is fundamental to building a system that works correctly. So far little investigation has been done in validating the techniques used for this purpose. Changes or additions to the knowledge base may involve extensive evolutionary modifications, and while new expert systems must be validated, changes to existing ones, especially when other subsystems are present, involve re-verification.

Four cautionary points about the success of using expert systems have been made by Firschein et al. (1986): (1) there exists a limited number of systems which go beyond the experimental stage; (2) these systems are not generalizable; (3) the knowledge which these systems represent is quite simple; and (4) while the existing programming tools are useful for simple systems is not yet apparent that they can be used for more complex, powerful and formalized systems.

Most implemented expert systems have served only static processes such as design, diagnosis, production and prediction. Few have dealt with dynamic systems such as continuous process monitoring and control. Apart from questions relevant to expert knowledge-based systems as such, there are also those common to all computer applications. These problems of software development should be addressed at the same time as the system is validated.

Some questions requiring testing and validation are: (1) the compatibility of input devices to the task in question; (2) the assignment of function keys, especially when interchangeability may lead to confusion, (e.g., when enter and return functions are assigned to the same key); (3) the ordering of menus and their terminology; (4) compatibility between menus and responses; and (5) incorporation of redundancy (such as requiring confirmation of a selected action) to reduce error.

3.3 Intravehicular and Extravehicular Activities

As previously suggested, general-purpose workstations will be difficult to design. However, costs for special and general-purpose workstations can be estimated (Hall, 1985) and used to compare with respect to the design and implementation of new technologies of operator performance in speed and accuracy.

Mission objectives, both short and long term, dictate the design and number of workstations required. Thorough task analysis of each mission's objectives and operational requirements (such as data management and the monitoring of scientific experiments) will indicate common aspects and may provide justification for general-purpose design. Hall (1985) has argued that increased sophistication of software-derived control and display systems may permit general, reconfigurable workstations to support a broad range of mission requirements.

Human performance depends upon the choice of controls and display characteristics. The answers to questions of control design, such as selection of keyboards, hand controllers and single versus multiple tasking; and to questions of display design, such as colour, digital versus analog display, resolution, display-lag time and density, depend on task analysis. One, often overlooked aspect of display and user-friendliness, is linked to the design of software-derived control which addresses such questions of operator-machine interface as commands and menus, special function keys, display layouts, and full-screen versus line editing, to name only a few.

Working outside the space vehicle poses unique ergonomic problems not encountered on earth or in the space station. Much depends on the pressurized space suit, and making changes to the suit may greatly influence the characteristics of the environment and the efficiency of EVA. For example, as it is designed at present, a space suit with its clumsy gloves precludes the use of keyboards. Perhaps the biggest problem relates to restraint because operators must be tethered, and so must tools and equipment, and this restricts the range of movements.

Monitoring and measuring operator performance (mental, physiological, social) in both IVA and EVA is crucial, if we are to more fully understand human productivity in zero-gravity conditions and we are to implement technological developments to enhance the efficacy of human performance.

3.4 Remote Manipulators

Telepresence means the use of a remote nonhuman operator such as a robot to perform human functions. As a new technological pursuit it holds promise for successful implementation and its ramifications for inclusion in a space station are far reaching. Given the nature of the space environment both inside and outside of the space station, human psychomotor abilities (in the face of exposure to extreme temperatures and toxins) will not meet performance requirements. To meet mission requirements successfully and efficiently remote manipulators must be correctly incorporated into the space station.

The major appeal of remote manipulators is that they allow operators to perform dangerous tasks in hostile and difficult environments, and to reach objects that would otherwise be in accessible. They reduce time spent outside the space station, reducing hazards to the operator, and permitting operations to continue at all times, even when specialized intermittent hazards occur.

Efficient control of remote manipulators depends on a high degree of direct and augmented feedback information, a point raised earlier. Operator control depends upon task lighting, sensory feedback (primarily visual), display design, hand controller design (providing feedback on forces, speeds, and tactual sensation), and workstation design. Selecting and capturing the appropriate sensory feedback is difficult and few designers have succeeded in accomplishing this at present. Determining the appropriate source and kind of feedback still needs to be done.

4.0 SOME COMMON MISCONCEPTIONS

This report has discussed a number of ergonomic questions as they relate to the special problems of space station and activity in space. In conclusion common misconceptions about the general role and validity of ergonomics in system development are outlined (Turpin, 1987).

First, ergonomics is vieved as being just common sense. Unfortunately, common sense cannot necessarily be trusted because, owing to direct or in direct research, ideas change over time. In any case, some common sense ideas are simply incorrect: people are not always good judges of what is best for them. Common sense has limits and seldom permits the anticipation and delineation of needs. While, undoubtedly, some improvements can be made on the basis of common sense, they do require validation.

Secondly, it is thought that extensive operator training on the level of the system will overcome problems that may have been overlooked during design. However, training is expensive and extensive training on unnecessarily complex procedures is unnecessarily expensive. Furthermore, the Challenger disaster demonstrated that extensive training does not prevent accidents.

Thirdly, a designer adopts the practice of consulting the operators on the assumption that if they work with the system it must be well designed. But operators are often avare of the cost and time of implementing a system and may accept it as it is, to avoid recriminations. Its inadequacies are then hidden until a critical incident arises. Furthermore, highly skilled individuals are likely to accept the challenge of overcoming the system deficiencies by their skills. Most often they will succeed, but under stress they are likely to resort to inappropriate habits and strategies.

Fourthly, as a variant of the previous tactic, the designer builds a system which he or she can operate, applying the principle that you only have to be human to be an expert in human factors. This approach ignores the fact that the designer may have characteristics not shared with regular operators, and the operator's perspective and view of the system is quite different. Ergonomic principles are not a question of what someone prefers, whether the someone is the chief engineer, the designer or the astronaut, but what sound research and development have shown to affect performance.

Fifthly, there is the practice of therapeutic rather than preventive ergonomics. Operators are trained to adjust to an inadequately designed system, rather than a system properly designed before implementation, and costly retrofits are made. Solutions to problems are sought after the event, on the basis of learning from mistakes, making changes to the system, and then reimplementing. But reimplementation often takes place without proper validation and one problem is replaced by another. In any case, learning by mistakes can be costly not only in materials but also in lives.

Lastly, the viev is taken that something is better than nothing, and nev technologies and procedures are applied before an ergonomic task analysis is done. This can lead to costly, unnecessary, and sometimes inappropriate design, because it is too easily assumed that nothing, in fact, already exists. Consider, for example, the situation where an astronaut gets sick. The astronaut can chose not to seek medical advice and not to administer self-treatment. Not treating is doing something, and it is possible that the astronaut will recover spontaneously and get better under this condition. Other possibilities

are that the astronaut prescribes self-treatment without medical advice or follovs treatment prescribed by a physician. The point is that all conditions must be compared in order to shov that one is particularly effective (as in a placebo design). Introducing a nev design implies first performing an ergonomic task analysis to determine what is already done and to demonstrate that a gain is to be made.

5.0 SUMMARY

Ergonomics is orientated towards fulfilling the needs (along several dimensions) of the human operator. Achieving this is without industrial boundary, requires task analysis, necessitates inclusion of the operator (the user) in development, implementation, and test phases, and requires critical evaluation of existing technologies.

Designing operational systems for space poses challenging and innovative opportunities for ergonomics because of the unique environment of zero gravity. Very little is known about human performance in this environment and in many cases technology must be pushed to its limit. Notwithstanding this, the pursuit of ergonomic solutions for the space environment is exciting and gives potential terrestrial spin-offs.

Major questions for space operational systems focus on feedback and errors, their integration with technology (e.g., remote manipulators), design of workstations for IVA and EVA with specific reference to generic prescription needs, and the pros and cons of automation and computerization.

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4

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SUMMARY/SOMMAIRE

This report outlines various aspects of operational systems in space stations as they influence, or are influenced by, operator performance and it discusses the application of ergonomics to the questions raised.

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